# Uncertainties and Interdisciplinary Transfers Through the End-to-End System (UNITES): Capturing Uncertainty in the Common Tactical Environmental Picture

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## LONG-TERM GOALS

UNITES is a unique, interdisciplinary team with expertise spanning the environment (physical oceanography and bottom geology), ocean acoustics (propagation, ambient noise, reverberation and signal processing), and tactical sonar systems.  The overall goals of the research are to enhance the understanding of the uncertainty in the ocean environment (including the sea bottom), characterize its impact on sonar system performance, and provide the Navy with guidance in understanding sonar system performance uncertainty in the littoral.

## OBJECTIVES

Specific objectives of the team effort are to:
1) Develop generic methods to efficiently and simply characterize, parameterize, and prioritize sonar system variabilities and uncertainties arising from regional scales (spatial and temporal) and processes.
2) Construct, calibrate and evaluate uncertainty and variability models, for the sonar systems and their components, addressing forward and backward transfer of uncertainties.
3) Transfer uncertainties from the acoustic environment to the sonar and its associated signal processing, in order to effectively characterize and understand sonar performance and predictions.

## APPROACH

Our technical approach is based on utilizing environmental probability density functions (PDF) to provide a description of sonar performance.  The PDFs will be determined for appropriate spatial and temporal scales as dictated by the systems under consideration.  In particular, these PDFs will be determined for the following: meso- and sub-mesoscale fronts and eddies, tides, internal tides, waves and solitons, interference variability (ambient noise and reverberation) and spatially variable bottoms. In FY03, we have worked with acoustic data from the 1996 Shelfbreak PRIMER exercise and the ASIAEX (Asian Seas International Acoustics Experiment) tests in the East China Sea (ECS).

## WORK COMPLETED

Abbot is one of two co-leaders of the UNITES Team and has worked closely with other team members.  In particular, the following are the OASIS accomplishments over the past year:

## Report Documentation Page

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- The sonar probabilistic performance prediction method, which incorporates environmental variability, has been briefed to fleet personnel and is presently under review by the Navy's Sensor Optimization Working Group. In particular, an end-to-end passive broadband sonar system operating in the ECS was evaluated and probability density functions for the transmission loss, ambient noise, source level and detector were developed (presented at the ONR Uncertainty Scientific Meeting Workshop, April 2003). Work has commenced on the evaluation of a narrow band passive sonar system.
- The azimuthal variability in acoustic transmission loss in the East China Sea has been shown to be significant based on analyses and interpretations of the ASIAEX data from the ECS (see Figure 1 and 2). However, the nature of the variability (oceanographic spatial-temporal effects versus spatially varying bottom effects) remains to be understood.
- Evaluation of the transmission loss probability density functions at three separate but close-by sites in the East China Sea suggest that these sites can be considered to be from the same acoustic uncertainty province.
- The Shelfbreak PRIMER data have been evaluated through the use of a vertical plane-wave beamformer (typical of a given system). The variability in the vertical has been shown to be strongly affected by the temporal variability in the oceanography (see Figures 3 and 4), and in particular, scattering from the internal wave field.

**RESULTS**

Figures 1a) and b) show the location in the East China Sea of the transmission loss (TL) measurements under consideration this year. Most noteworthy is the result shown in Figure 2. A circle track was conducted in ASIAEX (see Figure 1b) with an acoustic source ship maintaining approximately constant range of 30 km from the central point, where a vertical line array was placed. Broadband explosive shots were deployed from the source ship and the mean TL over 48° sectors is plotted in Figure 2 at a hydrophone depth of 83m (d/D = 0.75). In general, high loss is observed at azimuths of $030^o$ to $150^o$ and lower loss occurs at azimuths of $215^o$ to $350^o$. The figure shows that the resulting mean TL data are azimuth angle dependent. This is a striking result because the bottom was fairly flat (bathymetry slopes are negligible) and the oceanography fairly stable during the tests. It is operationally important from a detection/counter-detection perspective because azimuths exhibiting low TL could be exploited for threat detection and directions exhibiting high TL could be exploited to improve counter-detection. The standard deviation ($\sigma$) of the mean TL also exhibits significant azimuthal variability. In a direction along the bathymetric contour, $\sigma$ varies significantly in a manner suggesting that spatial bottom variability may be the dominant mechanism of the azimuthal TL variability.

Key results from the PRIMER experiment vertical plane-wave beamformer are shown in Figures 3 – 5. Histograms from two 10 hour time periods, one considered to be oceanographically "calm" and the other "active," were formed for the acoustic signal and noise as measured through the vertical plane-wave beamformer. The "active" period is shown to exhibit strong internal waves. In contrast, during the "calm" period, the temperature profile was fairly stable. Figure 4 a shows the classical "noise notch" as measured at the vertical array during the calm period. This notch is due to the inability of the sound from distant shipping to propagate in the horizontal (steering angle = 0°) when in a downward refracting environment. The signal (Figure 4b) also exhibits the notch even though the source was mounted close to the bottom, about 42 km away from the receiver array. When the oceanography is active, the noise and signal notches fill in, as shown in Figures 5a) and b). Thus the

vertical distributions of the signal and noise are strongly affected by the internal waves. We are presently evaluating whether the dominant mechanism is scattering from the internal waves, fish and/or the bottom.

## IMPACT/APPLICATIONS

The primary application is to assist the sonar "prediction community" by providing a probabilistic representation of sonar system performance. The present approach provides a systematic method to incorporate uncertainties due to the environment and to transfer the effects of these uncertainties, in the end-to-end problem through the sonar systems under consideration. The operator can thus use this information to operate the system more effectively and make more informed decisions on search, risk, expenditure of assets (weapons) and assumptions of covertness.

## TRANSITIONS

Rules-of-thumb, lessons learned, technical implications for effective environmental sampling strategies for the fleet and other tactical insights have been presented to appropriate fleet personnel. As mentioned above, the Sensor Optimization Working Group is presently evaluating our probabilistic approach for capturing environmental uncertainty in sonar performance predictions. If considered favorable, the method would be transitioned into the STDA (Sonar Tactical Decision Aid) program, sponsored by ASTO.

## RELATED PROJECTS

1- The STDA program is an applied program that is considering the effects of environmental variability.

## PUBLICATIONS

Abbot, P., Celuzza, S., Dyer,I., Gomes, B., Fulford, J., and Lynch, J., "Effects of East China Sea Shallow-Water Environment on Acoustic Propagation," IEEE Journal of Ocean Engineering, Vol. 28, No. 2, April 2003, pp 192 – 211.

The following presentations will be made at the special session on Quantifying and Accounting for Uncertainty in Underwater Acoustics Signal Processing, sponsored by the the IEEE Signal Processing, October 8 – 10, 2003:
Abbot, P. and Dyer, I, "Predictive Probability of Detection Under Environmental Uncertainty."
Gedney, C., Abbot, P., Lynch, J. and Chiu, C.S., "Evaluating the Correlation of Signal and Noise Amplitude Fluctuations in Littoral Acoustic Transmissions."
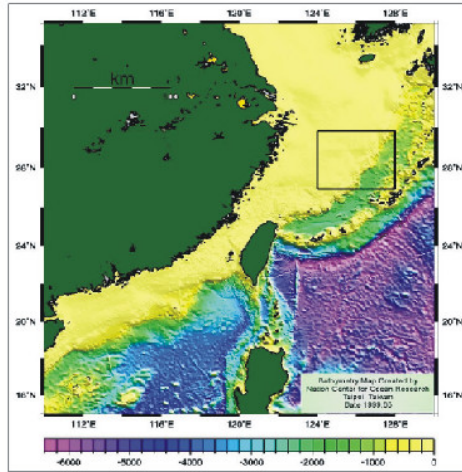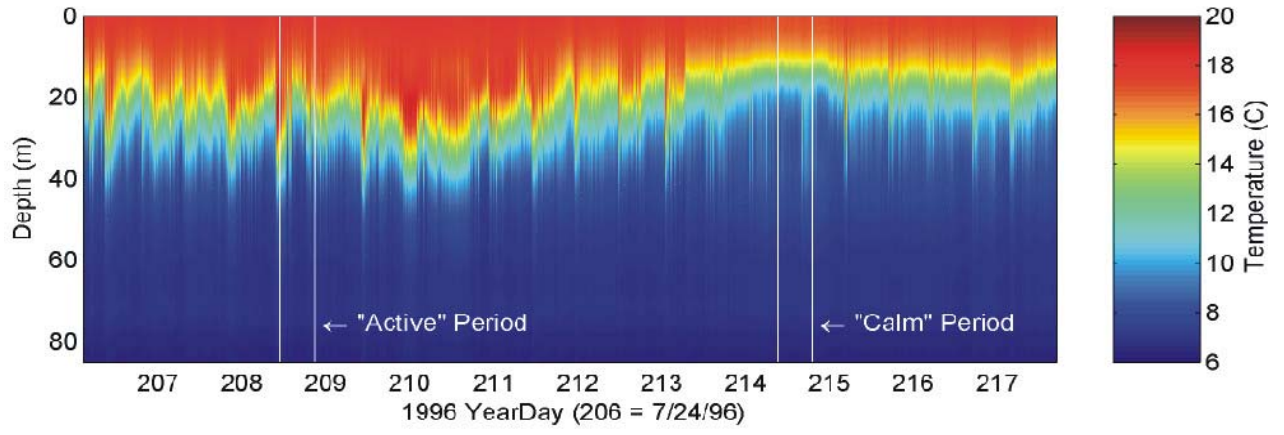
***Figure 1a General location in ECS for uncertainty analysis***
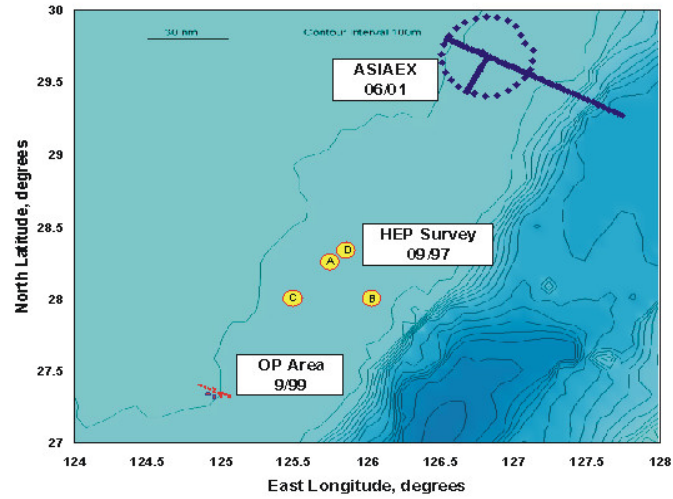
***Figure 1b Evaluation of the three sites shown suggest a similar acoustic uncertainty province***
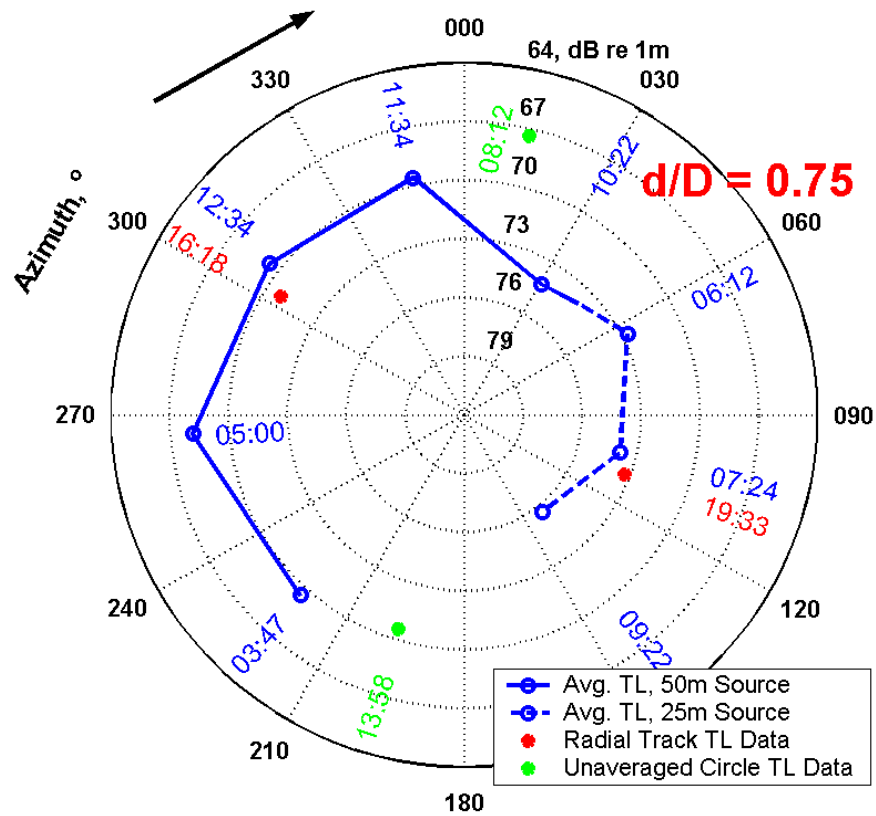


***Figure 2 Mean transmission loss in 48° sectors as a function of azimuth at R = 30km measured at the ASIAEX site (See fig1b). The TL data show a strong dependence on azimuthal angle***

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*Figure 3 Shelfbreak PRIMER vertical line array temperature profiles (from Chiu)*
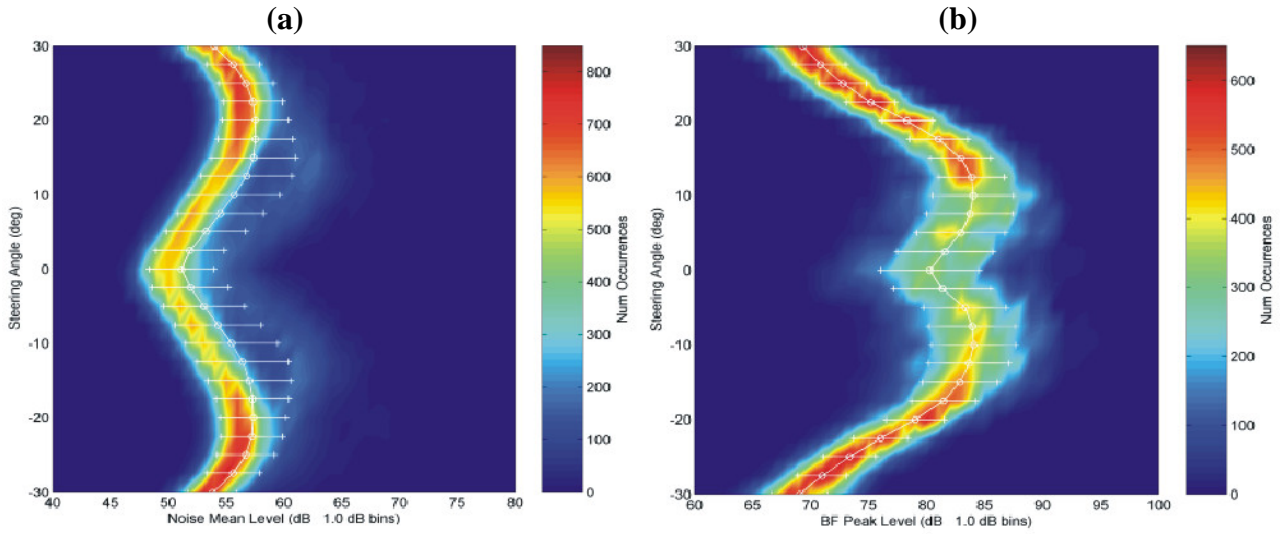


*Figure 4 Vertical beamformed histograms for the a) noise and b) signal, during the "Calm" oceanography period (See fig 3).*
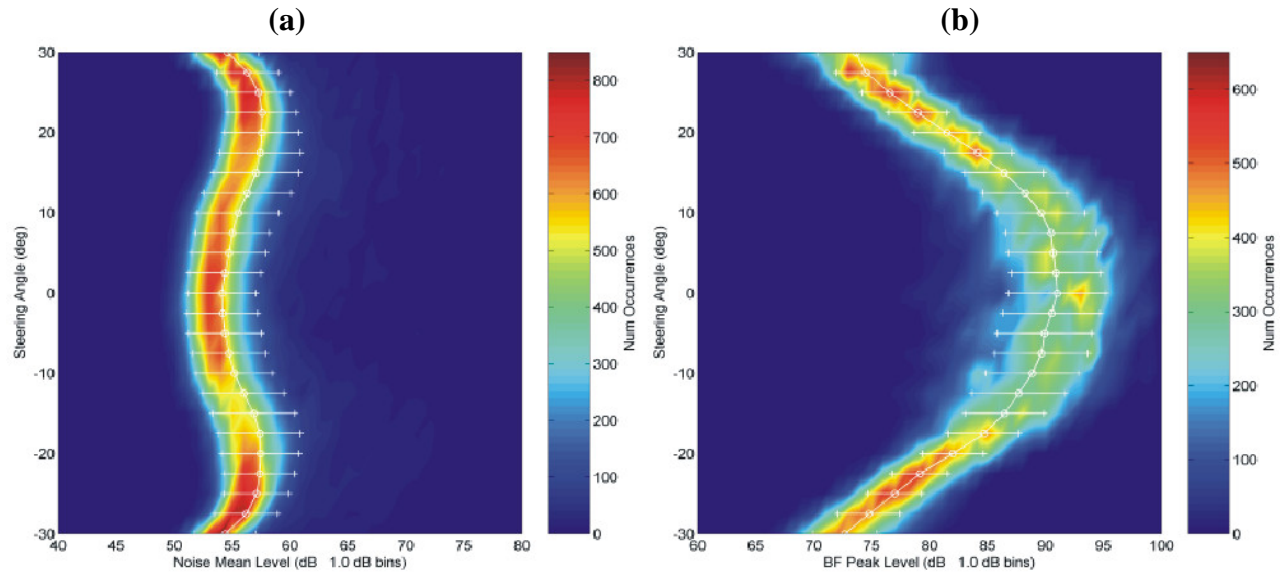
*Figure 5 Vertical beamformed histograms for the a) noise and b) signal, during the "Active" oceanography period (See Fig 3).*